EDUCATION FOR SUSTAINABLE DEVELOPMENT GOALS IN SPANISH ENGINEERING DEGREES

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ABSTRACT
EDINSOST and EDINSOST2 are two Spanish R&D+I funded projects. Their objective is to facilitate the training of graduates to be capable of leading the resolution of challenges in our society through the integration of sustainability training in the Spanish University System. Both projects focus, among other degrees, in engineering degrees. EDINSOST is organized around four specific objectives:
1) To define the Sustainability Competency Map of each engineering degree and establish a framework for incorporating the map into the degree curricula;
2) To validate didactic strategies for addressing sustainability from a constructivist and community pedagogical approach;
3) To diagnose the status of the sustainability training needs of faculty and develop and test training proposals
4) To diagnose the sustainability competency level of students and validate training proposals.
EDINSOST2 advances from developing sustainability competencies to develop SDGs learning objectives. It is currently in its early stages, so the results are preliminary. Although the data collection stage is over, the analysis of the collected data is still underway. This paper presents the main results of the EDINSOST project in the field of engineering education, and some preliminary results of EDINSOST2. In relation to the first EDINSOST objective, a sustainability competency map has been defined. Based on this map, the most appropriate didactic strategies for sustainability training have been analyzed and tested, and the state of the sustainability training requirements in teachers and students have been diagnosed. Proposals for training both groups will be developed in EDINSOST2.

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1. INTRODUCTION

1.1. Motivation

Contemporary society faces global challenges such as the economic crisis, climate change, desertification, deforestation, inequalities, wars and the eradication of poverty. In this global context, the promotion of Sustainable Development has gained broad international recognition as the way forward to ensure quality of life, equity between present and future generations and environmental health [1, 2]. Although the conceptualization of Sustainable Development remains controversial, a global consensus exists about the need to raise awareness and develop strategies and action plans to address the global challenges facing society today [1]. These changes are represented by the United Nations Agenda 2030 [3] and the Sustainable Development Goals (SDGs) approved by UNESCO [4] with the aim of being achieved in the year 2030. Achieving these objectives implies the need to establish action frameworks that facilitate an education for the participation, awareness and training of citizens.

The integration of Education for Sustainable Development (ESD) into Higher Education to achieve SDGs contributes to the development of university graduates’ skills related to sustainability, such as critical and creative thinking, problem solving, capability to act, collaborative competence and systemic thinking. This development will allow us to form potential agents of change, capable of shaping a more sustainable society.

In the past decade, much insight has been gained into the task that lies ahead. With hindsight, one might say that the approaches taken to institute sustainability in engineering education in the 1990s were somewhat naïve: Developing an add-on course, teaching other teachers about Sustainable Development and creating a track for Sustainable Development specialists are at best just the first step. The next steps to be taken in ESD should not only concern which course should be added to make engineering more sustainable in an always “crowded” curriculum, but also addressing the question of what type of curriculum might contribute effectively to Sustainable Development so that SDGs could be reached in 2030. Instead of adapting an unsustainable curriculum or introducing Sustainable Development, curricula should be rebuilt by benefitting from ESD expertise as the leading principle for curricula. This will not happen if faculty members are not equipped for the task. Dealing with Sustainable Development and social models helps faculty propose actions for improving the methodology and thereby enhance students’ competencies [5]. The full integration of Sustainable Development into a subject requires both sustainability content as well as suitable learning strategies. A focus on how we teach as much as what we teach is important, if we are to educate for Sustainable Development. Moreover, active learning strategies are necessary for creating the integrated and inter- and trans-disciplinary perspective required for sustainability education [6]. A set of guiding principles for the design of innovative active learning experiences may be drawn from the results of the Experiencing i-Design project described in Secundo et al. [7].
1.2. The EDINSOST projects

In order to achieve a better training of future engineers in terms of ESD, the EDINSOST project [8] started working in Spain in 2016 with four objectives:

- Objective 1 (O1): To define Sustainability Competency Maps for each of the participating degrees and establish a framework for incorporating the maps into the degrees in a holistic way;
- Objective 2 (O2): To validate different didactic strategies for addressing sustainability through a constructivist and community pedagogical approach;
- Objective 3 (O3): To diagnose the status of the training needs of each degree’s teachers with regard to sustainability, as well as to develop and test training proposals;
- Objective 4 (O4): To diagnose the sustainability competency level of current university students and to develop and test training proposals.

The EDINSOST project ended in 2019. That same year, the EDISNSOT2 project began. Society needs SDGs to be introduced into university curricula so that these can be achieved successfully in 2030. This is the main goal of EDINSOST2.

EDINSOST was an analysis project. EDINSOST2 is an intervention project. Its objective is to influence the design of various degrees and to analyze the results obtained at the end of the four-year duration of the project. EDINSOST2 has practically just started, so this paper only presents preliminary results related to one of its objectives: Identifying the SDGs in the EDINSOST’s sustainability competency maps.

Due to space limitations, this paper focuses solely on engineering degrees, despite the fact that EDINSOST projects have also developed tools for university degrees related to education and business.

2. METHODOLOGY

2.1. EDINSOST Objective O1

EDINSOST’s objective 1 is to develop Sustainability Maps for the degrees analyzed in the project. These maps characterize the sustainability competencies that students have to master to carry out their professional activity according to the principles of sustainable development. These maps have been designed on the basis of the four competencies related to sustainability defined by the Sectorial Commission CRUE-Sustainability [9]:

- C1: Critical contextualization of knowledge by establishing interrelations with social, economic, environmental, local and/or global problems.
- C2: Sustainable use of resources and prevention of negative impacts on the natural and social environment.
- C3: Participation in community processes that promote sustainability.
- C4: Application of ethical principles related to the values of sustainability in personal and professional behavior.

Each Sustainability Map contains a set of learning outcomes organized in a matrix. Rows contain competency units classified according to the three dimensions of
sustainability (social, environmental and economic) and the four CRUE sustainability competencies, while columns indicate the domain level of the learning outcomes according to a given taxonomy. The taxonomy used by EDINSOST is a simplified version of the Miller’s pyramid [10]. This taxonomy has three levels only: L1-Know, L2: Know-how and L3: Demonstrate + Do (the two upper levels of the Miller’s pyramid, demonstrate + do, have been integrated into a single level). The sustainability maps developed in EDINSOST for the different degrees involved in the study can be found in Sanchez-Carracedo et al. [11,12]. Table 1 shows the definition scheme of a sustainability competency in a Sustainability Map.

Table 1. Scheme of a sustainability competency in a Sustainability Map

<table>
<thead>
<tr>
<th>Competency</th>
<th>Dimension</th>
<th>Competency Units</th>
<th>Domain levels</th>
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<td>Economical</td>
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Each competency is addressed in the four dimensions indicated in Table 1, but in general, efforts have been made to work solely with the holistic dimension. Each dimension is defined by one or more Competency Units (CUs). Each CU’s domain level defines one or more Learning Outcome (LOs). In order to achieve the simplest possible Sustainability Map, we have tried to minimize both the number of CUs and LOs.

2.2. Objective O2

Pedagogical approaches used in our previous research were evaluated in order to validate the most effective didactic strategies [13]. Previous results showed that the more effective pedagogy for sustainability learning were those that are community oriented and apply constructive learning schemes. Taking this into account, we selected five teaching strategies in the EDINSOST project: Problem-Based Learning; Project-Oriented Learning; Service learning; Simulation; and Case Studies [14]. To evaluate their effectiveness, we analyzed 2 case studies of each pedagogical approaches and measured students’ learning through pre and post questionnaires. The questionnaires used were those defined for objective O4 below.

2.3. Objectives O3 and O4

To achieve objectives O3 and O4, several questionnaires have been designed adapted to both teachers and students. The questionnaires have been designed according to the learning outcomes defined in the Sustainability Maps. All the
questionnaires have passed a validation process. The validation has been carried out by a group of experts and by a students’ control group. Both groups have evaluated the relevance and clarity of the questions. An example of questionnaire for ICT students can be found in [15]. The questionnaire for engineering students consisted of 34 questions. The engineering faculty questionnaire integrates the questions corresponding to objectives O2 and O3, and consists of 62 questions.

2.4. EDINSOST 2

The Sustainability Maps developed in EDINSOST for the different degrees involved in the study [11,15] are the starting point for developing the objective O1 of the EDINSOST2 project. EDINSOST2 aims at introducing the SDGs in university degrees by aligning them with the learning outcomes identified in the Sustainability Maps. UNESCO [4] defined each of the 17 SDGs in the form of 15 learning objectives: 5 cognitive objectives, 5 socio-emotional objectives and 5 behavioral objectives. Together, a total of 255 learning objectives were defined. To achieve the objective O1 of EDINSOST 2, a matrix has been constructed which relates the 255 learning objectives defined by UNESCO [4] with the learning outcomes of the Sustainability Maps. In the case of engineering degrees, we discern when the Learning Objective of a certain SDG should be developed in all engineering degrees or only in some particular engineering degree.

3. RESULTS

3.1. EDINSOST Objective 1

Based on the learning outcomes defined in the Engineering Sustainability Map, the learning guides of all the subjects corresponding to the following six engineering degrees from three universities have been analyzed:

- Bachelor Degree in Electrical Engineering (BDEE) at the University of Córdoba (UCO) and Universitat Politècnica de Catalunya – BarcelonaTech (UPC).
- Bachelor Degree in Informatics Engineering (BDIE) at the UCO, UPC, and Universidad Politécnica de Madrid (UPM).
- Bachelor Degree in Mechanical Engineering (BDME) at the UCO and UPC.
- Bachelor Degree in Design Engineering (BDDE) at UPC.
- Bachelor Degree in Chemical Engineering (BDCHE) at UPM.
- Bachelor Degree in Industrial-Technologies Engineering (BDITE) at the UPM.

Figure 1 shows the presence of each sustainability competency defined by the CRUE in each of the degrees.
Figure 1 shows that no competency pattern can be discerned as no competency has the same level of presence for all degrees. However, C3 (Participation in community processes) is absent in 4 of the 6 degrees analyzed. On the other hand, C4 (Application of ethical principles) has a 100% presence in three degrees, and C2 (Sustainable use of resources) has a 92% presence in two degrees.

A comprehensive analysis of the presence of sustainability competencies in this set of engineering degrees can be found in [12]

3.2. EDINSOST Objective 2

The results are the definition of a methodology of didactic strategies for university education in sustainability and a table for each didactic strategy in which the guidelines for its correct application are indicated. To illustrate these results, Table 2 shows an example of the methodology employed for the Service-Learning strategy.

Table 2: Methodology of didactic strategies for university education in sustainability. Example for Service Learning

| Justification | It engages students in learning through a service to the community with a focus on justice and social and/or environmental responsibility, which produces a reciprocal benefit. |
**Challenge for students**
Engage students in the service to improve understanding of academic concepts through practical learning, as an instrument of social and political reform that promotes sustainable development and social justice.

**Work Modality**
Basically active, participatory, and reflective through collaboration in a project, with some individual tasks.

**Teacher’s role**
Tutor, facilitator

<table>
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<tr>
<th>1. Preparation Phase</th>
<th>1. Idea outline</th>
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<tbody>
<tr>
<td></td>
<td>1.2. Relationship with entities</td>
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<td>1.3. Project planning</td>
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<th>2. Execution Phase</th>
<th>2.1. Perform the service</th>
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<td>2.2. Relate to the people and entities in the environment</td>
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<td>2.3. Register, communicate and disseminate the project</td>
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| 3. Evaluation Phase | 3.1. Joint evaluation |

### 3.3. EDINSOST Objective 3

The questionnaire was applied to all the teachers involved in the degrees under study and in all the consortium universities where these degrees are offered. In engineering degrees, the questionnaire was applied to the University of Córdoba (teaching population: 211; sample: 26; participation: 12%), Universidad Politécnica de Madrid (teaching population: 2919; sample: 182; participation: 6%), and Universitat Politècnica de Catalunya-BarcelonaTech (teaching population: 3056; sample: 322; participation: 11%), which amounts to a total teaching population of 5,196, a sample of 530 questionnaires and a participation rate of 9%.

The questionnaire used a four-point Likert scale (totally disagree, strongly disagree, strongly agree and totally agree) to the statements concerning each of the competencies and Competency Units, and assesses the three domain levels of the Engineering Sustainability Map.

Results show that the majority of respondents (63%) agree with the statements; therefore, competencies have been acquired to some extent. However, 37% of respondents still disagree with the statements, so there is a clear need for training for that sample. The analysis by competencies shows (see Figure 2) that competency C1 (Critical contextualization of knowledge when establishing interrelations with social, economic, environmental, local and/or global problems) has been acquired to the greatest extent (71% agreement). The analysis also shows that competency C2 (Sustainable use of resources and prevention of negative impacts...
on the natural and social environment), with a 38% disagreement, has been the least acquired [8].

3.4. EDINSOST Objective 4

Objective O4 of the EDINSOST project tries to answer the question: How much do engineering students in the Spanish university system improve their sustainability skills during their studies at the university?

To achieve this objective, first and fourth year students from four degrees from three universities have been surveyed:

- Bachelor Degree in Informatics Engineering from the Universidad Politècnica de Catalunya - BarcelonaTech (UPC), the Universidad Politècnica de Madrid (UPM) and the University of Seville (US).
- Bachelor Degree in Mechanics Engineering from UPC and US
- Bachelor Degree in Chemical Engineering from UPM and US
- Bachelor Degree in Industrial Technologies Engineering from UPM and US

There have been 1157 responses from first-year students and 525 responses from fourth-year students who are taking their Bachelor Thesis. Results are shown in Figure 3.

Figure 3 shows the perception of engineering students about their competence in the four sustainability competencies. The gray bars correspond to first-year students, while the white bars show the improvement in skills perceived by fourth-year students.

The questionnaire responses were on a 4-point Likert scale, and were translated numerically on a 0 to 3 scale. Figure 3 shows that first-year students consider that they are approximately 50% proficient in the four competencies at the beginning of their studies. Fourth year students consider themselves a little more competent, but they barely achieve 66% of the result they should achieve (two out of three). Competency C4 (ethical principles) is the one in which students state that they feel
the least capable at, both in first and fourth grade, while competency C3 (collaborative work) is the one in which they declare themselves most capable. These data contradict those shown in Figure 1, which seems to indicate that the learning guides of the subjects do not reflect what the students really learn, or that the students are trained in sustainability outside the university.

![Bar chart showing learning increase for different competencies across courses.](image)

**Fig. 3.** Perception of first and fourth year students of engineering degrees about their learning in the four sustainability competencies

### 3.5. EDINSOST 2 Objective 1

Once the EDINSOST Engineering Sustainability Map has been defined, the first aim of the objective O1 of EDISNSOST2 project is to see how SDGs are present in the Sustainability Map. To do so, we analyzed whether the 255 SDG learning objectives corresponded to any of the learning outcomes on the map. Table 3 shows these results.
Table 3. Learning objectives of each SDG that must be developed in an engineering degree

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Table 3's rows show the learning objectives as they have been classified by UNESCO, numbered in order of appearance in the document [4]: Cognitive (C), Socio-emotional (S) and behavioral (B). The learning objectives highlighted in green and labeled as ENG correspond to the objectives that must be developed in some engineering degree. The learning objectives highlighted in red correspond to the objectives that must be developed in degrees of any educational level that are not related to engineering.

As can be seen in the table, there are SDGs very related to engineering (such as SDG 11-sustainable cities) and others that have little or no relationship (such as SDG 14-Life water).

4. CONCLUSIONS

This paper presents the results of the EDINSOST project and preliminary results of the EDISNSOT2 project. The projects encompass 13 degrees in 10 Spanish universities, in the fields of education, engineering, and sustainability.

The EDINSOST project had four objectives: (O1) to build the sustainability map of the degrees under analysis; (O2) to validate didactic strategies for learning sustainability; (O3) to diagnose the status of the sustainability training needs of teachers, and (O4) to diagnose the status of the sustainability training needs of students. The first objective has been completed successfully. Given the transversal nature of sustainability, four Sustainability Maps have been drawn up to address sustainability in all the degrees. The project analyzed how the different degrees fit their respective Sustainability Maps. In Objective O2, five teaching strategies were selected and analyzed: Problem-Based Learning; Project-Oriented Learning; Service Learning; Simulation; and Case Studies. For each didactic strategy, the project analyzed how it can contribute to learning sustainability and how it should be used to achieve this objective. To achieve Objectives O3 and O4, several questionnaires were designed, submitted to and answered by 858 teachers and 3,766 students. The questionnaires were validated beforehand and adapted to each degree. This data is currently being
analyzed. Several discussion groups were also organized with both teachers and students in order to conduct both a qualitative and a quantitative analysis from the answers to the questionnaires. Results reveal that there is a great disparity in the way in which sustainability is developed in the different Spanish university degrees. While some degrees include almost all subjects in developing sustainability, other degrees include only a few of them. Some degrees develop sustainability in elective subjects, while others also include it in compulsory subjects. It appears that teacher motivation plays a very important role, and sustainability is developed to a greater extent in those degrees taught by more motivated teachers. This fact implies that, with few exceptions, no guidelines are given in this regard from school management teams, and teachers are the one who finally decide, *motu proprio*, whether or not to develop sustainability in their subjects. Students perceive that sustainability is not developed properly in their respective degrees, a failing that is also due to their own self-assessed lack of knowledge about sustainability.

Results of EDINSOST2 project show that the Engineering Sustainability Map covers most of the 255 Learning objectives of the Agenda 2030 SDGs.

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